Project Proposal

The Realtime Hurricane Wind Analysis Project as proposed to the HPCC committee in September of 1997. Project milestones, deliverables and budget information have been omitted.

Abstract

Mitigating a portion of hurricane losses may be possible by effective use of monitoring information. Real-time analyses of measurements gathered from reconnaissance aircraft, land, marine and space observat ion platforms can help hurricane forecasters to identify communities that are going to experience the m ost severe winds and storm surge. Timely information on the actual areas impacted by a hurricane's eyewall and strongest winds at the earliest stages following a disaster should assist emergency managers in a llocating recovery resources, detecting potential search and rescue areas, and assessing storm damage be fore visual inspections are possible. In addition, archives of wind field analyses from recent storms can assist in scenario studies to evaluate mitigation strategies.

We envision a dynamic World Wide Web (WWW) user interface with security features. We conceive an interactive system which would allow scientific users to select a storm, focus on a particular time in the history of the storm in a graphical manner, examine and quality control the real-time data collected du ring the time period of interest, analyze and archive the wind field, and create a variety of graphical analysis products or data sets derived from the wind field. Emergency manager users would select from a menu of products derived from the wind field and formatted to facilitate input to GIS/ damage assessmen t software such as HAZUS from FEMA.

We will explore JAVA, Distributed Objects, and object-relational database technology to offer a distributed, dynamic, interactive, and platform-independent front end to the analysis system. We will develop a framework that facilitates the reuse of objects that employ scientific logic . These objects will be stored in an object-relational database. A prototype workstation client based system is already undergoing evaluation and a proposed database schema has already been designed.

For back end computational load sharing we will investigate the use of a distributed, object-oriented system over several distinct application, analysis, and database servers. Distributed objects are becomi ng more common in industry as a way to distribute components of processing over heterogeneous and geogra phically distant computing platforms. This allows a real-time system to be more robust because of the re dundancy of computational nodes (should one machine become unavailable another one can replace it) as we ll as more efficient because each platform is used to perform tasks best suited to its hardware. Portions of the system will be automated rather than interactive to facilitate transfer of the technology to th e National Hurricane Center as a tool for forecast and warning guidance. FEMA will provide advice on t he design of products needed to assist their mitigation and disaster decision-making activities.

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Problem Statement

Over the past ten years Tropical cyclones have caused losses averaging roughly $5 billion per year. The popularity of coastal living is exposing more and more people to tropical cyclones, making it difficult for emergency managers to educate, prepare, and evacuate vulnerable coastal residents and increasing the insurance industry's liability in a major hurricane disaster. Accurate forecasts of hu rricane landfalls can help those living in threatened communities to prepare their homes and leave areas subject to flooding, but damage will occur even if the forecasts are perfect. The response to the disast er depends on obtaining accurate and timely information on the magnitude and geographical distribution of the damage caused by the disaster. This information will determine which communities were most devastated and require immediate attention; it will also assist decision-making associated with the recovery process. Rapid-response visual damage assessment may be hampered by loss to the transportation and comm unication infrastructure. Satellite or aerial remote sensing of damage has potential for damage assessme nt but will require much ground truth and validation to become effective in a timely manner. To rapidly assess tropical cyclone disasters, physical measurements of the quantity forcing the damage is required. For hurricanes, the wind provides the forcing which builds waves and storm surge, buffets houses, and uproots trees.

Tropical cyclones are monitored globally by space-, aircraft-, land- and marine-based observing systems. Advances in computing and communications have made it possible to obtain these observations in near real-time. However, scientists involved in operational forecasting and basic and applied research on hurricanes have few tools that enable real-time interaction with, and analysis of, observations gathered in t ropical cyclones. Hurricane wind fields are determined subjectively based on the specialist's interpretation of flight-level reconnaissance data, satellite observations, pressure-wind relationships and available surface data. These fields are represented by text portions of the forecast product as radii (from the storm center) of 34 kt, 50 kt, and hurricane force winds in four compass quadrants relative to north. There is currently no operational objective method for assimilating and synthesizing disparate observations into a consistent wind field.

Emergency managers require accurate and fine scale wind field information to input to geographic infor mation systems (GIS) and damage models. GIS tools enable linking the storm information with demographics of the affected area and its infrastructure. Engineering models can make it possible to simulate damage to an inventory of generic types of structures within a disaster area. GIS tools and damage models would enable real-time damage assessments to assist decision makers with response and recovery planning and also serve as a tool to test mitigation strategies using scenario data sets. Emergency managers have access to only coarse scale information on the wind field through the wind radii information provided in NHC forecasts and advisories, and are considering the use of parametric models to provide more detailed wind field coverage. Wind models tend to oversimplify hurricane structure and do not adequately account for asymmetries in the wind field caused by convection, land-sea friction differences, and environmental wind shear. Furthermore such models may contradict the operational forecast information which could lead to confusion among emergency managers.

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Proposed Solution

We propose a real-time system for examining, synthesizing and objectively analyzing meteorological observations in hurricanes, using a common framework for wind exposure, measurement height, and averaging time. This system will allow scientists to interact with the observations, perform quality control, and select from a menu of several graphical products depicting meteorological fields for storm diagnosis and forecast guidance. Automation of several of the procedures will also make it possible to perform opera tional analyses on a regular 3 or 6 hour schedule consistent with NHC's warning and forecast cycle. For prelandfall cases, operational analyses could be combined with forecast error statistics and projected a long an envelope of potential storm tracks as a set of products for disaster planning. For hurricane l andfall cases, the system would provide a menu of products designed specifically for real-time emergency management damage assessment applications. These fields will be formatted to be readily input to GIS a nd damage modeling software such as FEMA's HAZUS.

This system would be a three tiered client-server application designed to accommodate a World Wide Web (WWW) or workstation client. All available wind measurements gathered by reconnaissance aircraft, satellite remote sensors, airborne Doppler radar, ships, buoys, coastal and inland automatic weather stations will be automatically downloaded, preprocessed, and stored using a modern object-relational database located on a dedicated server. One or more additional machines will be dedicated as an objective analysis server and an application server. The application server will use distributed objects to communicate act ions and events between the clients and the database and analysis servers. All data and analyses will b e archived on the database server and Java applets, Web Objects, and IDL will allow graphical and gridded products to be created dynamically from the analysis archive and delivered to the client "on the fly". This arrangement stores only the storm track and nodal wind components on the server, all products are quickly derived from these quantities and do not require storage.

Scientific users would interact with the data and archive through a hardware-independent Web browser client or by a workstation client. Emergency managers would interact with current products based on operational or poststorm analyses through a Web interface. For scenario studies, users could construct products searching the archive by year, storm name, storm category, or geographic area.

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Background

NOAA's Hurricane Research Division (HRD) has been producing real-time analyses of tropical cyclone surface wind observations on an experimental basis since 1993 (Burpee et al., 1994, Griffin et al., 1992) . The prototype application software is written in Objective-C utilizing the object-oriented NEXTSTEP/OPENSTEP user and development platform available for Intel, Sun, and NeXT hardware. This platform is the basis for Apple Computer's next modern operating system, code-named "Rhapsody".

Currently, the application engine first fetches data from a flat-file database, the data are then processed, quality controlled, and passed on to a VMS analysis server, and then displayed on a Tektronix terminal as a graphical product which is annotated and then transferred to NHC and printed for use by hurricane specialists. During the 1995 hurricane season 86 real-time analyses were produced, including five landfalling storms (Powell and Houston 1997). With partial automation of the analysis process, 134 analyses were conducted in 1996. An anal ysis requires the input of all available surface weather observations (e.g., ships, buoys, coastal platforms, surface aviation reports, reconnaissance aircraft data adjusted to the surface, etc.). Considerable man power is spent writing scripts to download data on a regular schedule and then process the data to fit the analysis framework. This includes the data sent by NOAA P3 and G4 research aircraft during the HRD hurricane field program as well as U.S. Air Force Reserves (AFRES) C-130 reconnaissance aircraft. These data are composited relative to the storm over a 4-6 hour period. All data are quality controlled and processed to conform to a common framework for height (33 feet), exposure (marine or open terrain over land), and averaging period (maximum sustained 1 minute wind speed) using accepted methods from micrometeorology and wind engineering (Powell et al., 1996a, Powell and Houston, 1996 b). This framework is consistent with that used by the National Hurricane Center (NHC), and is readily converted to wind load frameworks used in building codes.

The HRD analysis is still in the experimental or research stage, but it is quickly becoming accepted by a diverse user community as evidenced by:

1) Hurricane forecasters at NHC use the information in real time to help designate the location an d extent of maximum winds in warnings and advisories,

2) Storm surge specialists at NHC use the fields in real time to determine input parameters for the SLOSH model,

3) The Federal Emergency Management Agency (FEMA) has liaison officers on station at NHC during Hurri cane episodes who also view experimental real-time wind analyses created by the HRD. With the reque sted improvements listed in this proposal, it is possible that analysis products could be electronic ally transmitted to FEMA headquarters in formats compatible with geographic information systems imme diately following a hurricane disaster. This information could then be used as input to FEMA's disaster response strategies and damage assessment models and shared with state emergency managemen t agencies.

4) an experimental utility damage assessment model was created at the request of Florida Power and Light Company (FP&L). FPL will use input from the analysis system immediately followi ng a landfalling hurricane,

5) Post-storm analyses were used by the Insurance Institute for Property Loss Reduction to plan damage surveys following 1995 Hurricanes Erin, Marilyn, and Opal.
Intelligent use of real-time information is capable of saving millions in costs associated with disast er recovery. For example, FP&L estimated (Powell 1995) that even a 10% improvement in damage assessment accuracy after Hurricane Andrew could have saved ~$1 million in inventory costs; At the

recent ASCE Conf erence on Natural Disaster Reduction, a representative from State Farm Insurance mentioned that accurate in formation on the location and extent of the highest hurricane winds could save millions of dollars associa ted with sending adjusters into the field. The cost savings would obviously be dependent on the magnitude of the hurricane disaster but we believe that only a small segment of the public and government sectors are even considering the benefit of such information at present. An improved system would provide free access to a much wider segment of these communities following a hurricane disaster, resulting in even greater cost savings.

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Methods

Object-Oriented Approach

Modeling the real world through the object oriented (OO) paradigm has been a leading trend in the last decade of software development. Through the use of abstract data types and data encapsulation within class es of objects, objects represented in software send and receive messages to each other that are meaningful to them via "publicly visible" interfaces. Developing software in this manner helps programmers and designers alike by allowing the creation of intricately dynamic software with potentially reusable and modular code. Furthermore, the OO paradigm extends beyond the scope of the programming language to pervade the overall design philosophy. OO projects benefit in terms of code reuse, use of design patterns, rapid-development, more accurate estimation and more effective and efficient testing and maintenance. In light of these benefits and because vocabulary, notation and strategies are easily shared throughout an object oriented project, this project and its subprojects will use an OO iterative development method from beginning to end.

The project can be broken up into three basic subsystems: 1) Quality Control, 2) Analysis Automation, and 3) Output Generation (Powell et al., 1997). A subsystem groups tightly coupled classes of objects, such as those whose object instances frequently interact with each other, together so that the classes can be viewed as a single entity. A graphically-oriented Quality Control (QC) subsystem would be part of an application front end and reside and run on a client workstation or web browser. A QC session involves selecting desired observation types to be viewed, and determining a storm-track-based time window for viewing the data. All observations of the selected type can then be plotted in a storm-relative view for the chosen time window and geography is positioned for the center time. Decisions are made about data validity through visual nearest-neighbor comparison and inspection. Once the data are quality controlled, they would be passed, along with a storm track, through a series of Analysis Automation subsystem components. These components currently exist as stand-alone programs and would be distributed so as to allow access from different client machines. The Output Generation Subsystem would create graphical representations of various wind field based products via calls to off-the shelf data visualization software such as IDL. These calls should be embedded as external or internal database procedures written in a high level programming language. Using a database and the off-the shelf graphical software, we can easily deliver images on demand in a variety of standard formats.

In general, we will develop an object oriented framework designed to allow the construction of reusable objects that combine scientific logic with persistent data storage. More specifically, we will employ a highly portable object oriented programming language, object relational database technology and object distribution to offer a distributed, dynamic, interactive and platform independent product. We choose a primarily database-centric view of the project, client side platform independence and back end object distribution as our three focal points to briefly describe our proposed methods.

Database dependence

All aspects of the project will rely on a central database for most, if not all, data storage and delivery. The database approach to data archival provides several advantages over traditional file processing approaches. Among these are: 1) self description, a databases ability to not only contain data but to contain a description of itself, 2) insulation between programs and data, 3) data abstraction, 4) support of multiple views of the same data and 5) sharing of data and multi-user transaction processing. Furthermore, a good database system automatically solves many of the problems inherent in most data processing projects such as controlling redundancy, restricting unauthorized access, providing for persistent storage of program objects and data structures, representing complex relationships among data, and enforcing integrity constraints for the data (Elmasri and Navathe, 1994). HRD is currently investigating several off-the-shelf object-oriented and object-relational databases. Object-Oriented databases offer some advantages over relational databases; we will cite two: persistent object storage and inheritance. Edward Yourdon offers that the ideal solution for an OO system is an OO database because "every one of the 'persistent' classes and objects in the software would correspond exactly to a database object managed by the [OO database management system (OODBMS)]" (Yourdon 1994). This feature is important because all of a program's rich types must be converted to the more primitive types found in a Relational DBMS. This impedance problem, as it is sometimes called, presents a problem because it creates strong coupling between the application and the DBMS (Jacobson et al., 1992). The ability to use inheritance in an OO database is also an advantage in much the same way as it is to an OO application. It above all, promotes the concepts of reuse and specialization. Object-relational databases combine both philosophies (OO and relational) and tend to represent not only the best qualities of OO databases, but also those of relational databases, namely superior storage algorithms.

A preliminary database schema for a subset of the data to be used already exists and is the subject of a Masters Thesis at Florida International University (Morisseau-Leroy 1997). Two databases, one at AOML and one at NHC, should be used for redundancy in case of a landfall in the South Florida area or during periods of heavy use or inevitable outages.

Platform Independence

Platform independence and client side deployment on both workstations and the World Wide Web are integral parts of this project. A primary code implementation featuring Sun Microsystems' Java programming language is possible because its write once, run anywhere strategy lends itself to the simultaneous development and maintenance of workstation and web versions. With Java, the proposed application, or suite of applications, needs to be written only once and run either as a Java application when running the workstation version or as a Java applet embedded in HTML for the web version. Platform independent code coupled with web deployment will allow users to not only use any machine they want (as long as it supports the Java virtual machine), but also to be wherever they want on the Internet (as long as they have a web browser). Furthermore, we will explore the WebObjects technology from Apple Computer (http://software.apple.com/webobjects) for dynamic, server-side delivery of database information to the web. WebObjects is an integrated development environment for the world wide web including libraries and frameworks for building potentially complex applications that require access to databases and real-time data feeds. While JAVA may already address these issues, the use of WebObjects, which can incorporate JAVA, may help improve the speed of the applications when used on the web.

Distributed Objects

For back end computational load sharing, we will investigate the use of a distributed OO system over several distinct application, analysis, and data servers. Distributed objects are becoming more common in industry as a way to distribute components of processing over heterogeneous and geographically distant computing platforms. This allows a real time system to be more robust because of the redundancy of computational nodes (should one machine become unavailable another one can replace it) as well as more efficient because each platform is used to perform tasks best suited to its hardware. Distributed object (DO) technology will provide an immediate solution in the area of analysis automation. Initially, because of the time needed to port the analysis components to an OO programming language (OOPL), the current surface wind analysis programs, written in, FORTRAN 77, will most likely be wrapped in an OOPL and distributed such that each wrapped object acts as an agent for the scientific code that it contains and has access to the other objects in the system. HRD is currently investigating several DO options and will most likely side with a product that supports CORBA (Common Object Request Broker Architecture), IDL (Interface Definition Language) and IIOP (Internet Inter-Orb Protocol) for an industry standard system that can be distributed to clients over the Internet. A Masters Thesis addressing object distribution in a subset of the project is currently being proposed at Florida International University.

Maintenance, Deployment, and Distribution Issues

The operational version of the analysis system will require limited automated quality control and will run on a schedule consistent with NHC warning and forecast cycle. This part of the system will be coded (in FORTRAN) and maintained by NHC, and may use existing code elements supplied by HRD. This version of the analysis will incorporate flat files for data storage rather than a database

The interactive workstation/web version of the analysis system will be coded and maintained by HRD and evaluated at NHC and AOML. This version may be deployed or made available within NHC to interested scientists either as a web or workstation application. Most landfall products and archival products from past storms would be derived from the interactive version. HRD will maintain a database archive of past storms and make this information dynamically available over the Web.

Both automated and interactive versions should be capable of simultaneously handling multiple storms and geographic basins. For both automated and interactive versions of the analysis system, NHC, HRD, and FEMA will discuss dissemination and delivery of archived and real-time products including product design and content, uncertainty depiction, information security, and digital format for incorporation to GIS.

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Linkages

This solution conforms with the goal of NOAA's HPCC program to disseminate real-time and historical information to users more completely, in usable forms and in a timely manner through the Internet. The analysis system will help to fulfill NOAA's strategic plan objective to advance short-term warning and forecast services by improving customer service to the public, emergency managers, industry, the media, and private forecast planners through effective communication and utilization of NOAA's products.

This proposal addresses FEMA's goals to reduce loss of life and property and protect our nation's critical infrastructure from hazards through a comprehensive, risk-based, emergency management program of mitigation, preparedness, response and recovery. By working closely with FEMA's Mitigation Directorate this proposal is an example of a Federal partnership within the National Mitigation Strategy: "Partnerships for Building Safer Communities." The information provided on landfalling tropical cyclones is applicable to major FEMA mitigation initiatives in areas of hazard identification and risk assessment; applied research and technology transfer. It is critical for public safety that storm information exchanged between the agencies be consistent, accurate, timely, state-of-the-art, with some indication of an associated level of uncertainty.

The three year time period for the project was chosen to parallel FEMA 's development of a wind module to their HAZUS GIS software. In an effort to obtain matching funds for this HPCC proposal, HRD will be making a presentation (Sept. 11-12 in Dallas) to the panel of wind experts chosen to guide the HAZUS wind module effort by FEMA and the National Institute for Building Sciences (NIBS). When completed, HAZUS will be freely distributed to state and local emergency managers. Tropical cyclone analysis system products derived from real-time and archived wind fields will be designed for input to HAZUS. The wind module of HAZUS will allow storm information to be combined with geographic and demographic databases to produce specialized loss assessment maps for recovery management and the formulation of mitigation strategies.

These uses of storm information are consistent with a recent National Academy of Sciences (1996) report, "Computing and Communications in the Extreme" which identified challenges confronting crisis managers, including:

1) "need for cooperation among many different actors",

2) "need to rapidly identify, collect, and integrate crucial information about the developing situation", and

3) "capability to make projections and initiate actions in the face of an inevitable degree of uncertainty and incompleteness of information".

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Project-related References

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